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# Features of the development of the primary roots of wheat seedlings after the removal of abiotic electromagnetic stress

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The study considers the features of the development of the primary roots of spring wheat seedlings after pre-sowing exposure to a UHF EMF under conditions of pre-moistening of seeds. The object of the experiment was the seeds of soft spring wheat (*Triticum aestivum* L.) varieties Novosibirskaya 31, Alyoshina, Trizo, Iren, Pamyati Aphrodite, and Altayskaya 70. In the experimental variants, the duration of the microwave EMF (0, 5, 10, 15 s) and the seed moisture (15, 20, 25, 30%) were combined. The influence of the UHF EMF on the intensity of the development of the primary roots of spring wheat seedlings was significant. For example, one of the varieties (Triso) shows a slight decrease in the intensity of growth processes during a fifteen-second treatment. The decrease in root mass was 18.18% (moisture content 15%) and 2.20 times (moisture content 20%) compared to the control. Wheat variety Iren had a decrease in root weight relative to the untreated variant by 2.59 times (at a moisture content of 15%) and 7.33 times (at a moisture content of 20%). The features of root growth at the initial stages of plant development were variety-specific and also depended on the modes of microwave processing. An unfavorable variant of microwave irradiation was a combination of the duration of exposure of 15 s and the preliminary humidity of the processed grain of 30%. The variant of EMF exposure for 5 s stimulated growth processes in germinating grains expressed in a relative increase in the number of roots and their wet weight compared to the control. The variant of exposure to an EMF for 5 s stimulates growth processes in germinating grains, which is expressed in a relative increase in the number of roots compared to the control. This difference is 13.47% for the Novosibirskaya 31 variety, for the Trizo variety – 14.99%, Iren – 12.44%, Pamyati Aphrodite – 8.97%, and Alyoshina – 13.93% on average. According to the totality of the studied indicators, two varieties of spring wheat were distinguished: the variety of Pamyati Aphrodite as the most stable and the variety Alyoshina as the most plastic. The results obtained can be used in practical plant growing to increase the adaptive capacity of plants and, consequently, increase productivity. A well-developed root system will allow wheat to withstand adverse weather conditions and form a higher grain productivity.
**Keywords:** Growth, seedling, ultrahigh frequency electromagnetic field, humidity, root mass, number of roots.

## INTRODUCTION

Seed germination and the first stages of development of juvenile plants are decisive stages in the development of plants and can be considered as determining factors of their productivity. Morphometric changes accompanying this process are closely related to the survival of cereal seedlings and vegetative growth, which subsequently affects yield (Xie *et al*., 2017). The ultrahigh-frequency electromagnetic field (UHF EMF) with the preliminary selection of the optimal mode stimulates the processes of germination, growth, and development of plants, as well as the formation of crops (Cuglenok, 2019; Nikulina *et al*., 2017; Vasilenko *et al*., 2019). During seed hydration, reactive oxygen species (ROS) released are considered from two positions: as cellular messengers (Waszczak *et al*., 2018) or toxic molecules (Turkan, 2018), the production and accumulation of which can lead to inhibition or, conversely, stimulation of germination. The production of ROS not only accompanies the natural process of germination but is also additionally recorded under the action of many factors, including UHF EMF (Kataria, 2017; Tiwari *et al*., 2017).

Today the issue of the influence of UHF EMF on a plant and its organs in certain periods of ontogenetic development remains insufficiently studied. Physical processing methods can be used to effectively induce several physiological and

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biochemical changes in grain crop seeds, leading to an increase in digestibility, bioavailability, nutritional value, taste, and quality of cereal seedlings (Wang *et al*., 2019) used as microgreens – a functional supplement to the diet of modern man (Kondratenko *et al*., 2022). In addition, microwave treatment can neutralize the negative consequences of some stresses for plants, for example, osmotic stress (Chen *et al*., 2009). A feature of the use of UHF EMF in agricultural production is the need to consider the specific electrophysical, technological and biological properties of crops, the high heterogeneity of which significantly affects the action of electromagnetic energy and the final result (Bezpalko *et al*., 2019).

One of the most important phases of plant development is the initial one, from the moment of seed germination to the appearance of the first leaves and primary roots (Bareke, 2018). At this stage, the plant develops mainly due to the previously accumulated seed reserves. In addition to its reserves, the conditions under which germination takes place are of no small importance. Passing the first stage such as seed germination and the development of the first leaves and roots under adverse conditions often leads to the formation of defective plants, which affects the yield of such crops.

The use of morphometric parameters of seedling organs as a criterion for the productive properties of varietal seeds of cereal plants shows a close relationship with the yield of their crops (Larionov and Gorbataya,2012). An important component of the description of crops and varieties is the development of the primary root system of seedlings, which reflects the characteristics of the growth and development of an adult plant (Korobko and Mironova, 2015). Balueva (2020) proved the existence of a close correlation between the development of primary roots and sprouts of wheat and its yield since plant roots are critical in perceiving and responding to various external environmental stimuli through direct contact with soil moisture and nutrients. Individual methods of pre-treatment, for example, the influence of an EMF of UHF, play an important role in the intensity of the development of primary roots. Preliminary soaking of seeds before their subsequent microwave treatment is recommended for a more effective exposure to electromagnetic waves on the object (Aladjadjiyan, 2010).

In connection with the foregoing, the goal was to study the features of the development of the primary roots of seedlings of spring soft wheat after presowing exposure to a UHF EMF under conditions of preliminary moistening of seeds.

## MATERIALS AND METHODS

The studies were carried out in 2021 under the controlled microclimate conditions of the phytotron of the Kuzbass State Agricultural Academy. The work included the following stages: selection of an object (seeds of spring soft wheat became the object); preliminary selection of wheat varieties (we chose varieties cultivated in the Kemerovo region of the Russian Federation); preliminary selection of microwave processing modes; preliminary construction of the seed moisture curve based on our own experimental data; the actual conduct of the experiment. The seeds of soft spring wheat (*Triticum aestivum* L.) of the varieties Novosibirskaya 31, Aleshina, Trizo, Iren, Pamyati Aphrodite, and Altaiskaya 70 served as the object of the experiment. Since the final results of irradiation could be affected by the size and weight of the grains in the studied varieties, the weight of 1,000 grains was preliminarily determined, which amounted to: Novosibirskaya 31 – 37.2 ± 2.1 g, Alyoshina – 36.9±2.2 g, Trizo – 38.1±3.0 g, Iren – 37.8±2.6 g, Pamyati Aphrodite – 36.6 ± 2.3 g, and Altai 70 – 37.9 ± 3.1 g.

The action of two factors such as the duration of exposure to UHF EMF and seed moisture (before microwave treatment, the seeds were brought to the required moisture level (±0.5%)) was combined in the experimental variants. The power (0.7 kW) and frequency (2.45 GHz) of the magnetron (RF, Salyut NPP) at the Volna-100 microwave installation remained unchanged. The device used in the work of the microwave installation was such that the loose object moves along the conveyor belt, being exposed to radiation. The distance of the samples from the magnetron and the location of the seeds were set constructively and were not changed. Screening effects were not taken into account. At the time of irradiation, the temperature was not controlled. At the outlet, the temperature of the grain mass was selectively measured, which ranged from 38.0 ± 1.4 to 39.5 ± 1.4°C, using a FLIR TG165 thermal imager (USA) (with a temperature measurement error of ± 1.5%) (Isaev and Bastron, 2014). Small fluctuations in temperature are explained by some non-critical difference in architecture and seed size of different varieties of wheat. The total weight of seeds was 5 kg for each sample, from which five samples were taken using the envelope method, 100 g each, from which a combined sample with a total weight of 100 g was prepared. Then 50 grains were taken in triplicate.

The experiment scheme included the following options:

1. Control – grain 15% moisture, without processing;
2. Control – grain 20% moisture, without processing;
3. Control – grain 25% moisture, without processing;
4. Control – grain 30% moisture, without processing;
5. UHF EMF 5 s – grain 15% moisture;
6. UHF EMF 10 s – grain 15% moisture;
7. UHF EMF 15 s – grain 15% moisture;
8. UHF EMF 5 s – grain 20% moisture;
9. EMF 10 s – grain 20% moisture;
10. UHF EMF 15 s – grain 20% moisture;
11. UHF EMF 5 s – grain 25% moisture;
12. UHF EMF 10 s – grain 25% moisture;
13. UHF EMF 15 s – grain 25% moisture;
14. UHF EMF 5 s – grain 30% moisture;
15. UHF EMF 10 s – grain 30% moisture;

16. UHF EMF 15 s – grain 30% moisture.

The treated seeds were germinated on sterile moistened filter paper in Petri dishes under natural light conditions for 7 days. To determine the wet weight of the roots, 25 seedlings were separated without selection. Root length was not measured because it was not included in the scope of the study. The raw weight of the roots is an integrative total indicator. It takes into account both the length of the roots and their number; therefore, the last two indicators were not determined separately. All the roots that had developed by the time of analysis were cut off from the remains of the caryopsis, and their total wet weight for each plant was determined by the gravimetric method (Habieva *et al*., 2020) on an analytical balance VL-124 (Gosmetr, RF). Biological and analytical repetition of the determination of indicators was three times. The data are presented as arithmetic mean and standard deviations for three repetitions. A comparison of the samples was carried out based on the dispersion method using the F-test. Differences between the compared mean values were considered significant with a confidence probability of 95% or more ($P \leq 0.05$) (significant differences are indicated in the tables with *).

## RESULTS AND DISCUSSION

The intensity of growth of primary roots at the initial stages of plant development was not the same for the studied varieties. It differed in variety specificity (Table 1, Fig. 1 and 2). The genetic features of the variety affected the intensity of development of the underground organs of wheat seedlings. Thus, the highest average wet weight of the roots of untreated seedlings at a moisture level of 30% was demonstrated by the varieties Alyoshina, Altaiskaya 70, and Iren (0.079, 0.069, and 0.064 g, respectively) and the lowest – the varieties Novosibirskaya 31 and Trizo (0.019-0.022 g) (Table 1). Thus, the difference between them was 3.38 times on average. The difference within individual varieties was less significant. The differences between the untreated variants at a moisture content of 30 and 15% were 22.45% (Altayskaya 70 variety), 36.36% (Trizo variety), and 45.45% (Iren variety). An excess of 1.74-2.26 times was recorded for wheat varieties Novosibirskaya 31, Pamyati Aphrodite, and Alyoshina. There was a regular increase in the mass of the primary roots of seedlings with an increase in seed moisture since this technique includes part of the hydration period of the seed.

An analysis of the experimental options allows stating that the trends in the influence of microwave EMF on the fresh mass

**Table 1**. **Change in the wet weight of the roots of wheat seedlings under the influence of UHF EMF, g.**

| Duration of microwave treatment, s | | Seed moisture, % 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|
| Novosibirskaya 31 | 0 | 0.019±0.001 | 0.022±0.002 | 0.028±0.002 | 0.033±0.002 |
| | 5 | 0.023±0.002 | 0.026±0.002 | 0.035±0.002 | 0.043±0.003* |
| | 10 | 0.050±0.004* | 0.040±0.004* | 0.013±0.001* | 0.008±0.001* |
| | 15 | 0.010±0.001* | – | – | – |
| Trizo | 0 | 0.022±0.001 | 0.026±0.002 | 0.026±0.002 | 0.030±0.003 |
| | 5 | 0.042±0.003 | 0.037±0.003* | 0.037±0.003* | 0.053±0.004* |
| | 10 | 0.049±0.004* | 0.040±0.002* | 0.016±0.001 | 0.009±0.001* |
| | 15 | 0.018±0.001 | 0.010±0.001* | – | – |
| Iren | 0 | 0.044±0.003 | 0.057±0.004 | 0.061±0.005 | 0.064±0.004 |
| | 5 | 0.073±0.006 | 0.073±0.007* | 0.086±0.006* | 0.072±0.006 |
| | 10 | 0.043±0.003 | 0.040±0.002 | 0.029±0.002* | 0.020±0.001* |
| | 15 | 0.017±0.001* | 0.006±0.001* | – | – |
| Pamyati Aphrodite | 0 | 0.028±0.002 | 0.034±0.003 | 0.051±0.005 | 0.054±0.005 |
| | 5 | 0.054±0.004* | 0.057±0.004* | 0.081±0.007* | 0.058±0.003 |
| | 10 | 0.046±0.003 | 0.038±0.002 | 0.035±0.003* | 0.030±0.003* |
| | 15 | – | – | – | – |
| Altaiskaya 70 | 0 | 0.049±0.003 | 0.054±0.004 | 0.060±0.005 | 0.069±0.005 |
| | 5 | 0.051±0.004 | 0.055±0.004 | 0.041±0.003 | 0.042±0.003 |
| | 10 | 0.024±0.001* | 0.034±0.002* | 0.048±0.004* | 0.045±0.004 |
| | 15 | – | – | – | – |
| Alyoshina | 0 | 0.035±0.002 | 0.058±0.004 | 0.070±0.007 | 0.079±0.006 |
| | 5 | 0.085±0.007* | 0.062±0.006 | 0.067±0.005 | 0.060±0.005 |
| | 10 | 0.033±0.001 | 0.039±0.002* | 0.020±0.001* | 0.010±0.001* |
| | 15 | 0.008±0,001* | 0.009±0,001* | 0.006±0,001* | – |

* – significant differences in comparison with untreated plants, revealed at $p \leq 0.05$. A dash means the absence of primary roots at the time of measurement.

of roots are also variety-specific, but also depend on the treatment exposure. An unambiguously unfavorable mode of microwave irradiation can be considered the duration of exposure to 15 seconds. In two varieties (Pamyati Aphrodite and Altaiskaya 70), seed embryos treated with an EMF for 15 seconds die, regardless of the level of initial moisture content of the grains. The energy impulse received by them is too large. The found repeatability limit (at P = 0.95) for analytical repetitions does not exceed the calculated values; therefore, the result of discrepancies is explained precisely by the varietal characteristics of the seed material used.

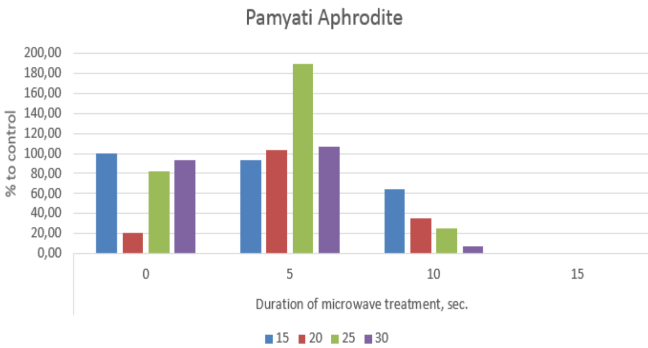


**Figure 1. Changes in the biomass of wheat roots of the Pamyati Aphrodite variety after microwave treatment, %.**

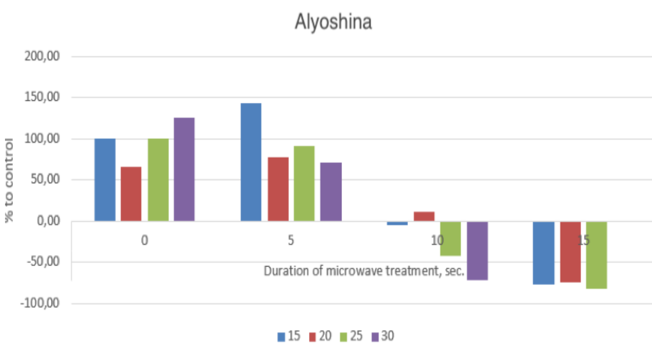


**Figure 2. Changes in the biomass of wheat roots of the Alyoshina variety after microwave treatment, %.**

The result obtained by us is still the result of the biochemical transformations of seedlings and not the thermal effects of the microwave device, which is also confirmed in other works. Thus, microwave irradiation in the plant *Arabidopsis thaliana* is reported to enhance the expression of the gene that regulates the change of growth phases (i.e., shortens the vegetative period by reducing the phenological phases of development) and does not affect the expression of genes involved in the plant response to heat stress (Horikoshi, 2019). The results of Horikoshi (2019) show that the effect of microwave irradiation on the growth of living plants is not related to the thermal effect. In the same work, the author convincingly proved that when acting on chemically pure substances that are not associated with living organisms, it is precisely the influence of electromagnetic radiation and not thermal exposure. In the work (Kaur *et al*., 2021), the features of signaling and the mechanisms of the formation of plant responses to EMF, including microwave range are considered.

One of the varieties (Trizo) demonstrates a slight decrease in the intensity of growth processes with a fifteen-second treatment. Compared with the control variant, the decrease in root mass occurred by 18.18% (moisture content 15%) and 2.20 times (moisture content 20%). For wheat of the Iren variety, a decrease in the mass of roots relative to the untreated variant was 2.59 times (at a moisture content of 15%) and 7.33 times (at a moisture content of 20%). Seeds of Novosibirskaya 31 wheat germinated after UHF EMF treatment for 15 seconds. However, they were able to form a small number of weak, thin, shortened roots, and therefore their weight decreased by 1.90 times compared to the control. The most resistant to prolonged irradiation were wheat seeds of the Alyoshina variety, which germinated at moisture levels of 15, 20, and 25%. However, they formed weak primary roots, which was expressed in their low fresh weight (from 0.006 to 0.009 g). The difference with the control was 22.86% on average.

Among all variants of microwave treatment, a regime was registered (exposure 15 s, humidity 30%), which has an adverse effect on wheat seeds of all studied varieties.

Table 2 shows the features of the formation of the number of primary roots of wheat seedlings. In general, for all variants and varieties, grains had from 2 to 6 roots during germination. However, small varietal differences were recorded, consisting, for example, of the range between the minimum and maximum observed values. Thus, this indicator ranged from 2 to 5 roots for varieties Novosibirskaya 31, Trizo, and Pamyati Aphrodite and from 3 to 6 for varieties of Pamyati Aphrodite, Alyoshina, and Iren (Table 2).

Wheat seedlings of the Pamyati Aphrodite variety form the smallest average number of roots in the absence of microwave exposure. These values range from 3.77 to 3.81 pcs. depending on humidity. The highest average number of roots in the control variant was recorded in varieties Iren and Altaiskaya 70: from 4.06 to 4.40 pcs (Table 2). The trends that describe the dependence of the number of primary roots on the level of preliminary moistening in the control variant do not differ in uniformity. A wide variety of trends is also noted in the experimental variants. It can be argued that the excessive duration of microwave treatment, which is 10 and 15 seconds, has a negative value for the number of seedling roots.

The variant of exposure to an EMF for 5 s stimulates growth processes in germinating grains, which is expressed in a relative increase in the number of roots compared to the

**Table 2. Change in the number of roots of wheat seedlings under the influence of UHF EMF, pcs.**

| Duration of microwave treatment, s | | Seed moisture, % | | | |
|---|---|---|---|---|---|
| | | 15 | 20 | 25 | 30 |
| Novosibirskaya 31 | 0 | 4.01±0.30 | 4.04±0.26 | 4.01±0.24 | 3.98±0.27 |
| | 5 | 4.44±0.31 | 4.61±0.25 | 4.59±0.29 | 4.48±0.23* |
| | 10 | 4.36±0.24 | 4.31±0.20 | 4.27±0.29 | 3.29±0.19* |
| | 15 | 2.21±0.16* | – | – | – |
| Trizo | 0 | 3.98±0.18 | 4.11±0.29 | 4.13±0.17 | 4.08±0.23 |
| | 5 | 4.66±0.20* | 4.68±0.22 | 4.69±0.26 | 4.51±0.20 |
| | 10 | 4.67±0.23 | 4.59±0.24 | 4.57±0.31 | 3.03±0.15* |
| | 15 | 3.14±0.12* | 3.03±0.11* | – | – |
| Iren | 0 | 4.16±0.29 | 4.21±0.26 | 4.18±0.22 | 4.40±0.24 |
| | 5 | 4.78±0.24 | 4.71±0.27 | 4.62±0.28 | 4.65±0.31 |
| | 10 | 4.13±0.30 | 4.11±0.20 | 4.07±0.23 | 4.03±0.25 |
| | 15 | 3.08±0.11* | 3.20±0.18* | – | – |
| Pamyati Aphrodite | 0 | 3.77±0.21 | 3.81±0.20 | 3.78±0.15 | 3.79±.016 |
| | 5 | 4.06±0.25 | 4.11±0.22 | 4.21±0.28* | 4.18±0.19* |
| | 10 | 4.16±0.21* | 4.21±0.22 | 4.17±0.32 | 4.17±0.29 |
| | 15 | – | – | – | – |
| Altaiskaya 70 | 0 | 4.17±0.24 | 4.42±0.13 | 4.06±0.29 | 4.24±0.23 |
| | 5 | 3.61*±0.17 | 3.28±0.18* | 4.17±0.20 | 3.76±0.18* |
| | 10 | 3.15*±0.15 | 3.24±0.19* | 3.61±0.16 | 3.62±0.11* |
| | 15 | – | – | – | – |
| Alyoshina | 0 | 4.01±0.24 | 4.08±0.21 | 3.96±0.15 | 3.94±0.16 |
| | 5 | 4.76±0.29* | 4.64±0.27* | 4.35±0.23 | 4.46±0.19* |
| | 10 | 3.78±0.19 | 3.86±0.21* | 3.71±0.15 | 3.12±0.14* |
| | 15 | 3.16±0.11* | 3.09±0.17* | 3.21±0.14* | – |

* – significant differences in comparison with untreated plants, revealed at $p \leq 0.05$. A dash means the absence of primary roots at the time of measurement.

control. For the Novosibirskaya 31 variety, this difference is 13.47% on average, for the Trizo variety – 14.99%, Iren – 12.44%, Pamyati Aphrodite – 8.97%, and Alyoshina – 13.93%. The only variety that reacted negatively to microwave treatment was Altaiskaya 70: compared with untreated seedlings, the number of roots decreased by 12.56% after the five-second microwave treatment and by 21.09% after the ten-second treatment.

It is necessary to dwell on the varietal features of the development of underground organs of juvenile wheat plants. So, according to the wet weight of the roots (average for all variants), the varieties Iren, Pamyati Aphrodite, and Altaiskaya 70 were distinguished, for which the highest average values were recorded – 0.047-0.049 g. A significant difference with these values was noted for wheat varieties Novosibirskaya 31 and Trizo with indicators 0.027-0.030 g, i.e. 1.68 times. Based on these indicators, one can indirectly judge the overall rate of development of the roots of these varieties under the action of stressors.

The contribution to the indicator of the wet weight of the roots is made up of two parameters: both the total number of primary roots that appeared by the fifth day of measurement and their total length and thickness. For example, during the experiment, a situation was often encountered when, with a large number of roots, they turned out to be thin and/or short, which reduced the total root biomass. On the contrary, compensation for a relatively small number of roots could occur due to an increase in their length and/or thickness. In any case, the wet weight of the roots is an integrative indicator that summarizes the various characteristics of the development of the root system of juvenile plants. When growing in the field, plants with more developed roots will be in more favorable conditions compared to other plants. A well-developed root system, even at the first stage of cereal development, makes it possible to make better use of spring soil moisture, switch to an autotrophic type of nutrition earlier, and more intensively absorb nutrients from the soil. These advantages, in turn, will make it possible to reduce the negative impact of adverse weather factors during the passage of critical phenophases by cultivated cereal plants (Soboleva, 2017).

Thus, according to the totality of the variability of the studied indicators, two varieties of spring wheat are distinguished: the variety of Pamyati Aphrodite as the most stable and the variety Alyoshina as the most plastic. Our data confirm long-term field studies carried out under different edaphic and

weather conditions and showed high plasticity and responsiveness to the improvement of cultivation conditions for wheat varieties Alyoshina and Iren, which is characteristic of varieties of the intensive type (Melekhina *et al.*, 2015). We also note the low plasticity of the Pamyati Aphrodite variety, which allows it to be classified as an extensive variety.

The data obtained in the experiment allow us to take a fresh look at the long-known processes of development of higher plants. Thus, the positive effect of individual microwave field modes on seed germination has been known for a long time and has been successfully used in crop production. However, for the first time, the need to take into account the initial moisture content of the seed material has also been proved. In addition, the data obtained indicate that the reaction of different wheat varieties to the effect of these factors differs. Thus, in practice, it is necessary to take into account a set of factors affecting the germination of cereal seeds, if it is necessary to obtain the most intensive growth of the root system of seedlings.

***Conclusion:*** The influence of the UHF EMF on the intensity of development of the primary roots of spring wheat seedlings is significant. Features of root growth at the initial stages of plant development are variety-specific and depend on the modes of microwave treatment. An unfavorable option for microwave irradiation is a combination of exposure duration of 15 seconds and preliminary moisture content of the processed grain of 30%. The variant of exposure to an EMF for 5 s stimulates growth processes in germinating grains, which is expressed in a relative increase in the number of roots and their wet weight compared to the control. According to the totality of the studied indicators, two varieties of spring wheat are distinguished: the variety of Pamyati Aphrodite as the most stable and the variety Alyoshina as the most plastic.

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***Ethical statement*****:** Not applicable.

***Availability of data and material*****:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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***Code Availability:*** Not applicable.

***Consent to participate*****:** Not applicable.

***Conflict of interest:*** There is no conflict of interest to declare.

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